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BIRD IMPACT TESTS
OF VULCAN AIRCRAFT
WINDSCREENS

by

I. I. McNaughtan

D. A. Perfect

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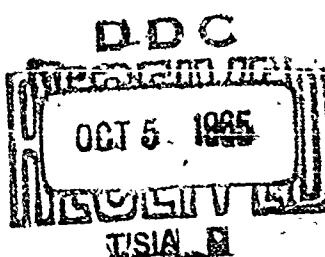
MINISTRY OF AVIATION

FARNBOROUGH HANTS

U.D.C. No. 629.13.012.134 : 620.178.7 : 593.2

R O Y A L   A I R C R A F T   E S T A B L I S H M E N T

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July 1965

BIRD IMPACT TESTS OF VULCAN AIRCRAFT WINDSCREENS

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SUMMARY

A description is given, and results presented and disou~sed, of a series
of tests made to evaluate the bird impact resistance of Vulcan windsoreens. The
investigation included both dry air sandwich and gold film type panels impacted
with 1 lb, $2\frac{1}{2}$ lb and 4 lb birds.

2

<div align="center">CONTENTS</div>

1 INTRODUCTION

A statistical review[1] of aircraft damage resulting from collision with birds has shown that the risk of collision decreases with increase in altitude and is greatest at altitudes below 500 ft. With the adaptation of the Vulcan aircraft to the role of low level penetration the risk of collision with a bird was greatly increased. The aircraft specification had not required that the windscreen should be resistant to bird impact It was therefore requested by the Ministry of Aviation, D(RAF)B that an investigation be made to determine the degree of protection provided for the pilots by the existing Vulcan windscreens against the impact of birds during low altitude cruise flight.

Since the windscreens of the Vulcan B Mk.1 and B Mk.2 are significantly different, from the aspect of bird impact, it was necessary to test specimens of both types of construction. The tests were made at the R.A.E. by firing "birds" from a compressed air gun against windscreen panels mounted in a stationary Vulcan windscreen frame member. The temperature conditions simulated low level flight during winter or after high altitude cruise which is the condition in which the minimum degree of protection is provided by the windscreen.

2 DESCRIPTION OF TEST SPECIMENS

2.1 Vulcan windscreens

Similar windscreen mounting frames are fitted to B Mk.1 and B Mk.2 Vulcan aircraft, but the windscreen panels are not of the same construction in both Marks of aircraft. As shown diagrammatically in Fig.1 and in Fig.2 there is a total of 5 transparent panels in the windscreen assembly of which 2, the lower rear panels, are small D.V. windows which were not included in the bird resistance investigation. The three main transparencies consist of a flat centre panel approximately 12" wide x 24" long at an impact angle of 51° (the angle between the line of flight and the normal to the windscreen), and two flat side panels, one ahead of each pilot, approximately 12" wide x 21" long at an impact angle of 56°.

In the case of the B Mk.1 Vulcan the centre and side panels are of similar construction and method of edge attachment to the windscreen frame. The panels are of dry air sandwich construction and are shown in detail in Fig.3. The two main strength members are the 0.25" thick layer of poly-vinyl-butyral (P.V.B.) and the 0.75" thick layer of sweep toughened glass. The innermost layer of the panel can be either a single pane of 3/16" strengthened glass or a sandwich laminate of 2 mm glass and 0.02" P.V.B.: samples of both types were tested

in the investigation. The use of dry air sandwich construction is detrimental
to the bird impact resistance of the P.V.B. layer of the windscreen. The high
thermal resistance of the air gap which results in the inner surface of the screen
having a temperature not greatly different from that of the cabin, and thereby
achieving freedom from misting, also results in the layer of P.V.B. attaining a
temperature that is not greatly different from the indicated outside air tempera-
ture (O.A.T.). During flight with low O.A.T. the temperature of the P.V.B. layer
is therefore well below the optimum (45-50°C) for the bird impact resistance.

The centre and side panels of the B Mk.2 Vulcan are of gold film type and
have construction details and mounting attachment as shown in Fig.4. The main
strength members are the 0.25" layer of P.V.B. and the 0.75" layer of toughened
glass. The use of the gold film heater for demisting results in the temperature
of the P.V.B. layer being maintained at 50°C which is within the optimum range
of temperature for P.V.B. bird impact resistance. The gold film heating layer
for the side panels is divided into three zones each fed from a separate phase
of a 3 phase A.C. supply. Due to the shape of the panel the three zones are
not equal in area and one is shorter than the other two and requires a lower
supply voltage (see para. 3.2).

2.2 Test specimens

In order to provide representative support for the windscreen panels during
bird impact testing a windscreen frame casting was secured by bolts to a $\frac{1}{2}$" thick
duralumin plate which was bolted to the rigid steel channel structure of the bird
impact test facility (Fig.2). The test panels were mounted in the frame in the
standard aircraft manner. Before installation the attachment fittings were
carefully inspected for damage from previous tests and all damaged fittings
were replaced by spares.

The mounting structure was arranged so that the line of fire of the
compressed air gun was parallel to the duralumin plate and that impact was on
the centre of the panel under test. Provision was made to allow testing of
either the starboard, centre or port windscreen panel. With this arrangement
the impact angle of the test windscreen panel corresponded to that with the air-
craft in level flight at low altitude cruise speed.

3 TEST PROCEDURE

3.1 Impact test procedure

The tests were made in the R.A.E. bird impact test facility which is
described in Appendix A. The target is stationary and the "bird" projectile
is fired from a 6" bore compressed air gun.

Three types of bird projectiles were used in the investigation:-

(a) 4 lb bird: consisting of a $3\frac{1}{2}$ lb chicken together with a 7 oz foam plastic barrel plug contained in a nylon bag. Total weight 4 lb 0 oz.

(b) $2\frac{1}{2}$ lb bird: consisting of a 2 lb chicken together with a 7 oz foam plastic barrel plug contained in a nylon bag. Total weight 2 lb 8 oz.

(c) 1 lb bird: consisting of a woodpigeon in a nylon bag. Total weight 1 lb 0 oz to 1 lb 2 oz.

In all cases the birds had been stored in deep freeze and thawed out for 24 hours at 25°C prior to firing.

3.2 Temperature simulation and control

In order to simulate the temperatures of the assembly during flight at low altitude in cold weather two methods were used. In the case of tests made during the winter with the shade temperature at mid-day below 5°C the specimen was assembled and allowed to stand in the open overnight (temperature -2°C to 2°C). It was then tested in the open, in the shade, at the prevailing air temperature. For tests made in warmer weather the test assembly was completely shrouded with a box structure containing a fan and trays of solid CO_2, and cold air was circulated round the assembly until the mounting frame temperature fell to 0°C. The condition was then maintained for a period of 20 minutes to ensure that the P.V.B. layer had achieved a representative temperature.

In the case of tests of dry air sandwich panel specimens the box structure was removed and the test made within a period of 60 seconds. It is considered that in this short exposure to warm air there was little significant rise in the temperature of the P.V.B. layer either in the attachment joint or in the bulk specimen.

The test procedure was modified in the case of the gold film type specimens to include a heating period. As described in para. 2.1, the gold film heater consisted of three areas arranged electrically for connection to a 3-phase electrical supply. The necessary variable voltage electrical supply system was assembled to allow selection of "low heat" on the side screen (71 volts on the short phase and 81 volts on the others) and "medium heat" (101 volts on the short phase and 115 volts on the others). After exposure to low temperature for the 20 minute stabilising period the heater was energised to low heat for 10 minutes. The box structure was then speedily removed and medium heat applied for a period of 1 minute or until the temperature **sensing**

elements indicated that a temperature of 50°C had been achieved. The test was then made. This test procedure for the gold film panels was adopted to simulate windscreen temperature in the case of bird impact shortly after take-off.

Measurement of the temperatures of the panel surfaces, the frame surfaces and inside the edge attachment joints was made using copper-constantan thermocouples. For surface temperature measurements the thermocouple beads were attached to the surface with adhesive tape. Air temperatures were measured with mercury in glass thermometers. The temperature of the P.V.B. layer of the gold film type specimens was measured by means of the resistance thermometer elements built into the panels and normally used for temperature control purposes.

4 RESULTS

The results of the tests on dry air sandwich panels are given in Table 1 and of the tests on gold film panels in Table 2. In Tables 3 and 4 the results of the tests on one type of panel (centre or side screen) with one bird projectile are equated to other panels and bird weights by the methods described in para. 5.1 below. In these tables the following damage categories have been used.

(a) Complete failure: the projectile penetrated the panel and large fragments together with severe spalling were scattered rearwards. Fig.5 typifies this damage. (Test 1 on dry air sandwich panel)

(b) Severe damage: the panel was penetrated and considerable spalling was observed. Fig.6 typifies this damage. (Test 3 on gold film panel.)

(c) No penetration: the panel was not penetrated. At the upper end of this category limited spalling of the inner pane was observed of which Fig.7 (D.A.S. Test 6) is typical. At the lower end the damage was slight and no spalling resulted, Fig.8 (G.F. Test 4).

The theoretical impact resistance values listed in Tables 3 and 4 were calculated using the recommended formulae[2] for the case of impact with a 4 lb bird.

(a) For toughened glass

$$T = 0.136 \ (1-0.348 \cos \alpha) \ \text{antilog}_{10} \ V \cos \alpha/202$$

and (b) For poly-vinyl-butyral

$$T = 0.05 \ \text{antilog}_{10} \ V \cos \alpha/300$$

where T = layer thickness in inches

V = penetration speed in mph

α = impact angle

The results of the temperature measurements are given in Table 5.

5 DISCUSSION

5.1 Effect of bird weight and impact angle

In order to economise in the number of specimen panels required in the investigation, two assumptions were made to allow interpretation of one test result in terms of different bird weight and of alternative screen position.

These assumptions were:-

(a) $M V^3$ = constant

and (b) $V \cos \alpha$ = constant

for constant damage.

The first of these assumptions, that the product of bird weight and the cube of impact velocity is constant, has been indicated in a number of experimental investigations[3] for bird weight in the range 1 to 8 lb.

The second assumption that the product of impact velocity and cosine of the impact angle is constant, is based on the assumption that damage is proportional to the impact energy normal to the panel surface. Test results[3] have generally confirmed this, especially when the range in impact angle is small as in the case of the Vulcan centre and side panels.

Using these two assumptions the individual test results of Tables 1 and 2 were expanded to give calculated equivalent speeds as listed in Tables 3 and 4 to allow closer comparison of the variables.

5.2 Dry air sandwich windscreen panels

Seven specimens of dry air sandwich construction were tested and the equivalent results listed in Table 3 are in good agreement with one another. It is possible to draw a reasonable distinction between no penetration and severe damage to give a limiting speed-bird weight envelope for the Vulcan B Mk.1 windscreens. The estimated resistance values of Table 3 are plotted in Fig.9 to indicate the maximum speed at which protection of the pilots can be expected for various bird species with outside air temperature at or below 5°C. In setting the limit for protection between satisfactory

performance and serious damage as defined in para. 4 above it has been assumed
that the pilots personal equipment will protect him against the limited spalling
which will occur. If the criterion is no spalling the limiting speeds would be
some 30-50 kt lower than those indicated in Fig.9.

It can be seen from Table 3 that the estimated resistance of the windscreen
is much less than the theoretical formula for P.V.B. bird impact resistance
would indicate; but this result was expected since the temperature of the P.V.B.
during the tests was much lower than the optimum at which the theoretical
resistance is calculated. It was observed in the tests that the P.V.B. layer
acted as a brittle material and no signs of energy absorption by elongation
of the P.V.B. were observed. A feature which is more significant is that
estimated resistance is also much less than the theoretical value for the
toughened glass layer itself. This is attributed to the design of the panel
mounting attachment which is unsatisfactory from the bird impact aspect. (It
must be noted that the windscreen was not designed to be bird-proof.) The
support for the toughened glass pane is inadequate (see Fig.3). Strengthening
of the clamp frame, replacement of the individual sponge rubber washers by a
continuous washer, decrease in bolt pitch and an increase in the clamp frame
bearing area on the inner glass face could result in an improvement in the
resistance of the main glass pane.

Since the toughened glass pane was inadequately supported and the P.V.B.
layer inadequately clamped it is considered that the resistance of the screens
would not be increased from the estimated values under conditions simulating
warm outside air (15 to 25°C) and Fig.9 can be assumed to apply under all low
altitude flying conditions.

It was observed that the single inner pane of strengthened glass shattered
to a greater extent than the equivalent sandwich pane which should be used in
preference to the single pane.

It was noted that impact on the centre screen did not result in any damage
to either of the side screens. The windscreen frame appeared adequately strong
and was undamaged after the total of 17 test firings except that in the first
test against each panel position a light metal fairing strip at the top edge of
the frame was detached. It is understood that this fairing strip is not fitted
to production aircraft.

5.3 Gold film windscreen panels

Ten panels were tested and the equivalent results, for the side screens only,
are listed in Table 4 Although the assumption $M V^3$ = constant is not strictly

applicable over the bird weight range it is considered that the slight degree
of disparity is due to variations in both the degree of attachment support
and the attachment temperature in the various individual tests. It is possible
to assess the limiting speed for protection against 4 lb and 2 lb birds with
reasonable accuracy. In the case of the 1 lb bird the assessment is less
accurate but since the speed is in excess of 400 kt the error is probably not
significant. The values of limiting speed are plotted in Fig.10 for both the
side panel and the centre panel on the assumption that V cos α is constant.
No tests were made on centre panels in this case.

It is accepted that the use of the V cos α relationship to correlate
results from the side panel and centre panel is not strictly correct since
the panel shapes and sizes are different. However the correlation is good
in the case of the dry air sandwich panels and it is considered that adequate
accuracy is provided to allow use of the method in the case of the Vulcan
panels.

The resistance of the toughened glass layer is more or less in agreement
with the theoretical value i.e. crazing of the main pane occurred at approxi-
mately the theoretical penetration speed for the toughened glass layer. This
implies that the support of the main glass pane was better in the case of the
gold film screen than in that of the dry air sandwich screens. Comparison of
Figs.3 and 4 shows that this appears to be so.

The resistance of the panels to bird impact is inferior to the theoretical
value for P.V.B. despite the fact that the gold film heater raised the tempera-
ture of the bulk P.V.B. layer to 50°C - a value within the optimum range for
P.V.B. of this thickness[3]. This reduction in performance is attributed to two
main causes:-

(a) The strength of the edge attachment was inadequate at the top edge
panel.

The clamp frame was not a continuous member as in the case of the dry air
sandwich panels but consisted of two sections, a U-shaped section with the top
missing and a short straight section which supported the top edge but left the
two upper corners of the panel unsupported. The electrical connections to the
gold film heater and to the temperature control elements were fitted into these
corners. Fig.11 indicates how this lack of support at the top edge of the
panel was a weak point and led to failure of the panel under impact load.

and   (b) The temperature of the P.V.B. layer in and adjacent to the
attachment joint was well below the optimum value. This can be seen clearly
by reference to the temperatures listed in Table 5.

The effect of cause (a) above was also demonstrated in Test 9 where the
O.A.T. was raised to $30^{\circ}C$ in order to raise the temperature of the P.V.B. layer
in and adjacent to the attachment joint. Partial failure of the P.V.B. layer
at the top edge of the panel occurred for the impact of a 4 lb bird at 249 kt
(Fig.11(a)). It is therefore considered that the limiting speeds of Fig.10 can
be assumed to apply to all types of low level operational flying (i.e. summer
as well as winter).

Test 10 indicated that the panel provided superior impact resistance for
impact below the centre than for impact at the centre. It is considered that
impact near the top or near the outboard edge would be more severe than impact
at the centre. The speed values quoted in Figs.9 and 10 are therefore approxi-
mate values only.

It was observed that the degree of spalling and fragmentation of the
inner glass pane was much less in the case of the gold film specimens than it
was with the dry air sandwich specimens.

6   CONCLUSIONS

6.1   The degree of protection against bird impact damage provided for the
pilots of Vulcan aircraft by the main windscreen panels was determined and is
shown in Figs.9 and 10. For the screens directly ahead of the pilots the
maximum speed in knots for which protection is provided is

	Bird weight		
	4 lb	2 lb	1 lb
Vulcan B Mk.1	200	250	310
Vulcan B Mk.2	250	320	420

6.2   In addition to providing information on the bird impact resistance of
Vulcan windscreen the investigation confirmed a number of assumptions and
design recommendations of value in the design of transparencies to resist
impact by birds. The main features are

(a) Adequate support of toughened glass panes under bird impact load
is essential if the full potential resistance of the glass is to be realised.

(b) The edge mounting attachment at the top and top rear edges of panels requires careful design to ensure adequate support since it is in these areas that initial failure of the P.V.B. layer is most likely to occur.

(c) The temperature of the P.V.B. in and adjacent to the edge attachment is of importance in evaluating the impact resistance of the windscreen.

(d) The assumption $M V^3$ = constant is valid for evaluating windscreen performance under impact with birds weighing 1 to 4 lb.

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Appendix A

DESCRIPTION OF R.A.E. BIRD IMPACT TEST FACILITY

A.1 General

In the R.A.E. bird impact test facility the bird projectile is fired from a compressed air gun against a stationary target. The test therefore represents impact loads only. Aerodynamic loading due to forward speed is not fully represented whereas it is in the sledge type facility where the specimen is propelled into a stationary bird.

A.2 Bird gun

The bird gun is of 6" bore and has a 50 ft long barrel fitted with a rotating breech mechanism for loading the bird projectile. The compressed air reservoir of 33 ft^3 capacity can be pressurised to 450 lb/in^2 and is separated from the breech by a double diaphragm firing system consisting of two thin aluminium diaphragms, each capable of withstanding half the reservoir pressure, with the pressure between them adjusted to half that in the main reservoir. On pressing the firing button a quick acting electrically operated valve opens the diaphragm interspace to a small high pressure air supply, the outer diaphragm is then overloaded and fails followed rapidly by failure of the inner diaphragm and the projectile is accelerated down the barrel towards the target. The gun in fixed and the target mounted in position to give impact on the desired point. Impact speeds of up to 1000 ft/sec (600 kt) can be achieved with birds in the range 1 to 4 lb in weight.

A.3 Timing apparatus

Impact velocity is measured by the bird projectile cutting two wires on a timing stand positioned between the gun muzzle and the target. The time interval between breaking the wires is measured by a standard Chronaton Type 2SE microsecond timing unit. The accuracy in speed measurement is estimated to be ±2%

A.4 Bird projectile

A.4.1 4 lb Bird

The 4 lb bird projectile consists of a 3½ lb chicken together with a 7 oz foam plastic barrel plug contained within a nylon bag. The total weight of the projectile is adjusted to 4 lb 0 oz immediately before firing by the addition of wet cotton waste.

The foam plastic barrel plug is used to ensure an accurate fit of the projectile in the barrel of the gun and thereby obtain repeatable velocity/gun pressure characteristics which ensures that the required impact velocity is achieved in the test. The purpose of the nylon bag is to prevent breakup of the bird before it impacts on the target.

A.4.2 $2\frac{1}{7}$ lb bird

The $2\frac{1}{7}$ lb bird projectile is similar to the 4 lb projectile in all respects except that the chicken weight is 2 lb and the total weight is adjusted to 2 lb 8 oz before firing.

A.4.3 1 lb bird

The 1 lb bird consists of a wood-pigeon wrapped in a nylon bag and the weight generally varies in the range 1 lb to 1 lb 2 oz depending on the weight of the wood-pigeon. It is fired from the gun in a split hollow sabot of foam plastic material which accurately fits the barrel, thus providing reliable velocity prediction, and which opens up and breaks apart to allow the bird only to impact on the target.

A.4.4 In all cases the birds are stored in deep freeze until required for test. They are removed from the freezer 24 hours before use and warmed up in a temperature of $25^{\circ}C$ to ensure that they are adequately thawed out before firing.

Table 1

RESULTS OF TESTS ON DRY AIR SANDWICH PANEL SPECIMENS

Shot No.	Panel	Screen temp °C	Bird impact lb oz	Impact speed kt	Result
1	Centre	5	4 0	258	Penetration. Screen fragmented into large pieces one of which weighed 7 lb 13 oz (Fig.5).
2	Stbd	2	2 8	269	Penetration. Inner pane destroyed and severe spalling from main glass pane.
3	Port	3	1 2	262	No penetration. No damage to main glass pane. Only slight spalling from inner pane which was of sandwich type.
4	Centre	−3	4 0	211	Penetration. Inner pane destroyed. Main pane spalled badly with one large fragment.
5	Centre	−3	2 8	269	Penetration. Screen fragmented into large pieces one of which weighed 9 lb 8 oz.
6	Port	−1	4 0	177	No penetration. Inner pane (single pane type) completely destroyed. Main pane crazed but did not spall (Fig.7).
7	Port	−2	4 0	192	No penetration. Inner pane (single pane type) destroyed. Main pane crazed with slight spalling.

Table 2

RESULTS OF TESTS ON GOLD FILM PANEL SPECIMENS

All tests made on starboard side panels: temperatures listed in Table 5

| Shot No.	Bird weight lb oz	Impact speed kt	Result
1	4 0	228	No penetration. No damage to main pane. Slight crazing of inner pane but no spalling.
2	4 0	285	Penetration at top of panel. All panes crazed and severe spalling.
3	4 0	269	Penetration. Failure at top edge and upper sides. All panes crazed and inner pane spalled. (Fig.6)
4	2 8	285	No penetration. Inner and outer panes extensively crazed. Main pane not crazed. No spalling of inner pane (Fig.8).
5	2 11	285	No penetration. All panes crazed and part failure of vinyl at top edge. Slight spalling. Estimated that failure nearly occurred.
6	1 0	478	No penetration. All panes crazed. Spalling from inner pane.
7	1 0	456	No penetration. All panes crazed. Negligible spalling.
8	1 0	423	No penetration. All panes crazed. Slight spalling from inner face.
9	4 0	249	No penetration. All panes crazed. Partial vinyl failure at top edge. No spalling (Warm O.A.T.).
10	4 0	262	No penetration. All panes crazed. Little spalling from inner face. Impact 3" below panel centre.

Table 3

CALCULATED EQUIVALENT VALUES: DRY AIR SANDWICH SPECIMENS

Test results					Equivalent velocities for different bird weight: kt					
					Centre screen			Side screen		
Test	Panel	Bird lb oz	Speed kt	Result	4 lb	2 lb	1 lb	4 lb	2 lb	1 lb
1	Centre	4 0	258	Complete failure	258	325	440	290	366	461
2	Side	2 8	269	Severe damage	204	258	324	230	290	365
3	Side	1 2	262	No penetration[1]	153	192	242	172	216	272
4	Centre	4 0	211	Complete failure	211	266	336	238	299	378
5	Centre	2 8	269	Complete failure	230	290	364	259	325	440
6	Side	4 0	177	No penetration[2]	157	199	250	177	224	281
7	Side	4 0	192	No penetration[3]	170	215	271	192	242	305
				Estimated resistance	175	220	275	200	250	310
				Theoretical value for glass	234	295	372	262	332	448
				Theoretical value vinyl at 45°/50°C	288	364	456	326	440	518

1 Inner pane did not disintegrate.

2 Inner pane did disintegrate.

3 Inner pane did disintegrate and it is estimated that penetration nearly occurred.

Table 4

CALCULATED EQUIVALENT VALUES: GOLD FILM SIDE WINDSCREEN SPECIMENS

Test	Bird lb	oz	Speed kt	Result	Equivalent velocities for different bird weights: kt		
					4 lb	2 lb	1 lb
1	4	0	228	No penetration	228	288	362
2	4	0	285	Complete failure	285	360	453
3	4	0	269	Severe damage	269	339	427
4	2	8	285	No penetration	244	308	387
5	2	11	285	No penetration	250	315	398
6	1	0	478	Damaged	300	378	478
7	1	0	456	No penetration	286	360	456
8	1	0	423	No penetration	265	334	423
9	4	0	249	No penetration[1]	249	314	396
10	4	0	262	No penetration[2]	262	330	446
				Estimated resistance	250	320	420
				Theoretical value for glass	262	332	418
				Theoretical value for P.V.B.	326	410	518

1 O.A.T. + 30°C

2 Impact 3" below centre.

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Table 5 - TEMPERATURE MEASUREMENTS: GOLD FILM SPECIMENS
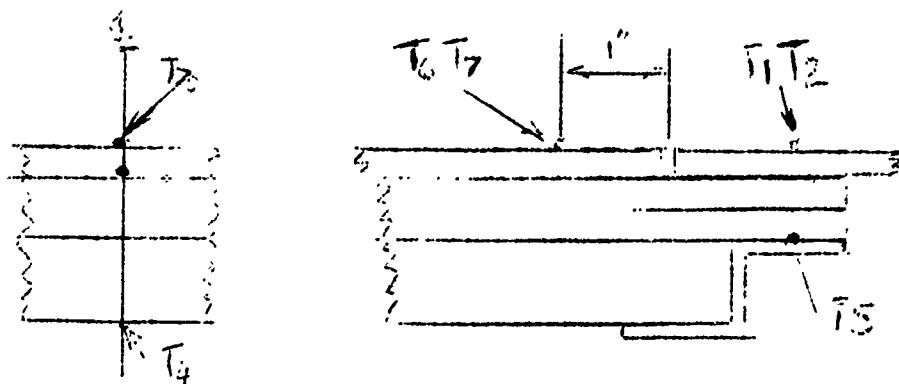
Shot No.		T_1	T_2	T_3	T_4	T_5	T_6	T_7
1	a	- 5	- 5	2	5			
	b	- 6	- 6	37	6			
2	a	- 4	- 4	- 1	+ 1			
	b	0	- 3	44	10			
3	a	- 9	- 9	- 6	- 2			
	b	- 9	- 9	35	+ 1			
4	a	- 5	- 5	- 3	+ 3			
	b	- 5	- 5	35	8.5			
5	a	- 1	- 1	0	4	-	0	0
	b	0	- 1	39	9	-	9	25
6	a	- 4	- 3	- 3	2	+ 1		
	b	- 2	- 2	39	8	- 1		
7	a	0	0	1	2			
	b	3	5	33	10			
8	a	0	1	2	4			
	b	4	2	36	9			
9	a	O.A.T. +30°C						
	b							
10	a	- 7	- 7	- 4	0			
	b	- 9	- 9	30	1			

a   After 20 min cold soak with $T_1 < 0°C$

b   Values when control temperature reached 50°C
(shortly before firing).

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| No.	Author	Title, etc.
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2	Staff of M.E. Dept	The design of aircraft transparencies for resistance against impact by birds and hailstones. RAE Technical Note No. ME 106, April 1952
3	I.I. McNaughtan	The resistance of transparencies to bird impact at high speeds. Aircraft Engineering V 36, p 409, December 1964

SIDE PANEL
12" WIDE X 21" LONG
$\alpha = 56°$

CENTRE PANEL
12" WIDE X 24" LONG
$\alpha = 51°$

D.V. PANEL.

α_2

α_1
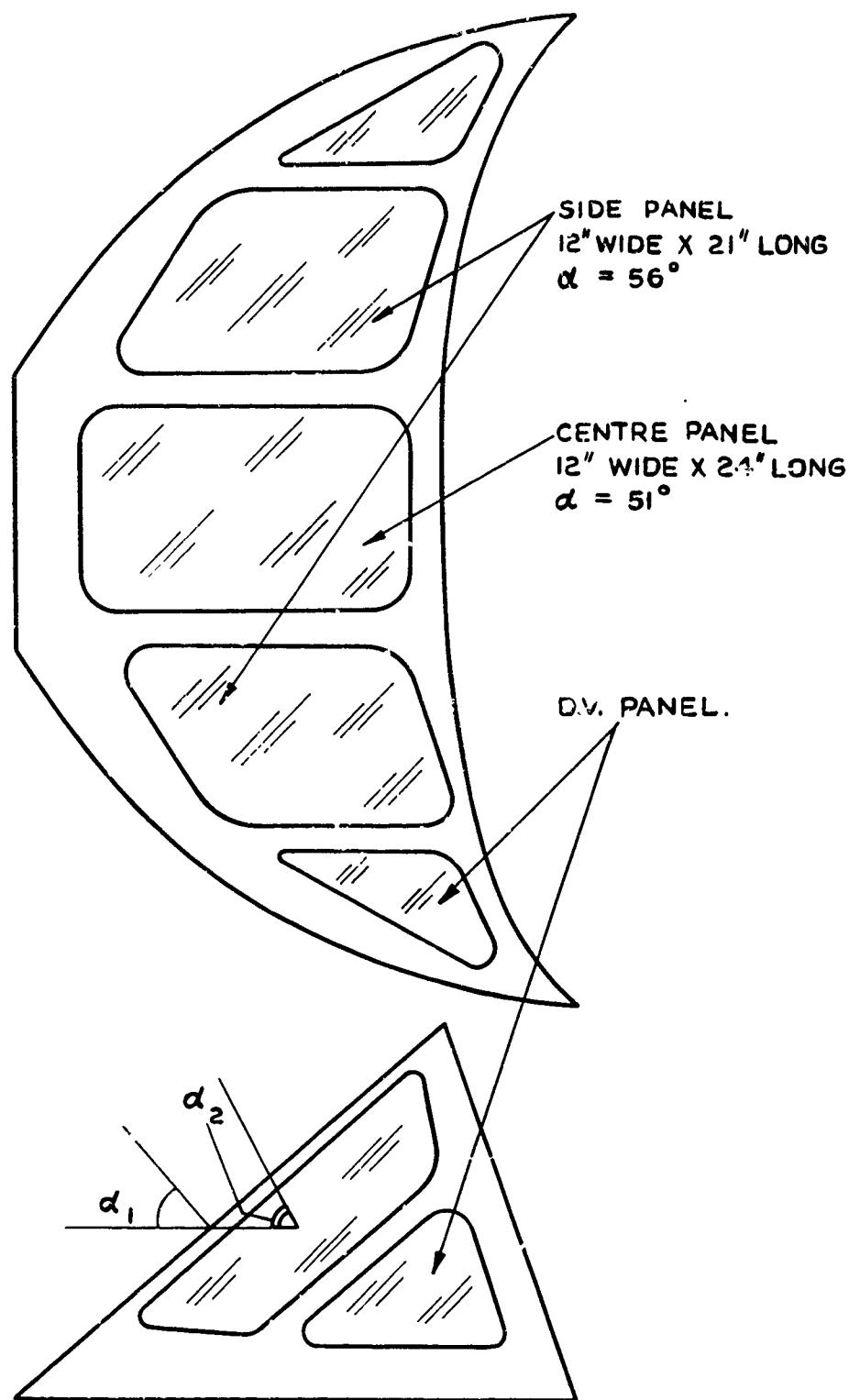
FIG.1   VULCAN WINDSCREEN MOUNTING   DIAGRAMMATIC

Fig.2
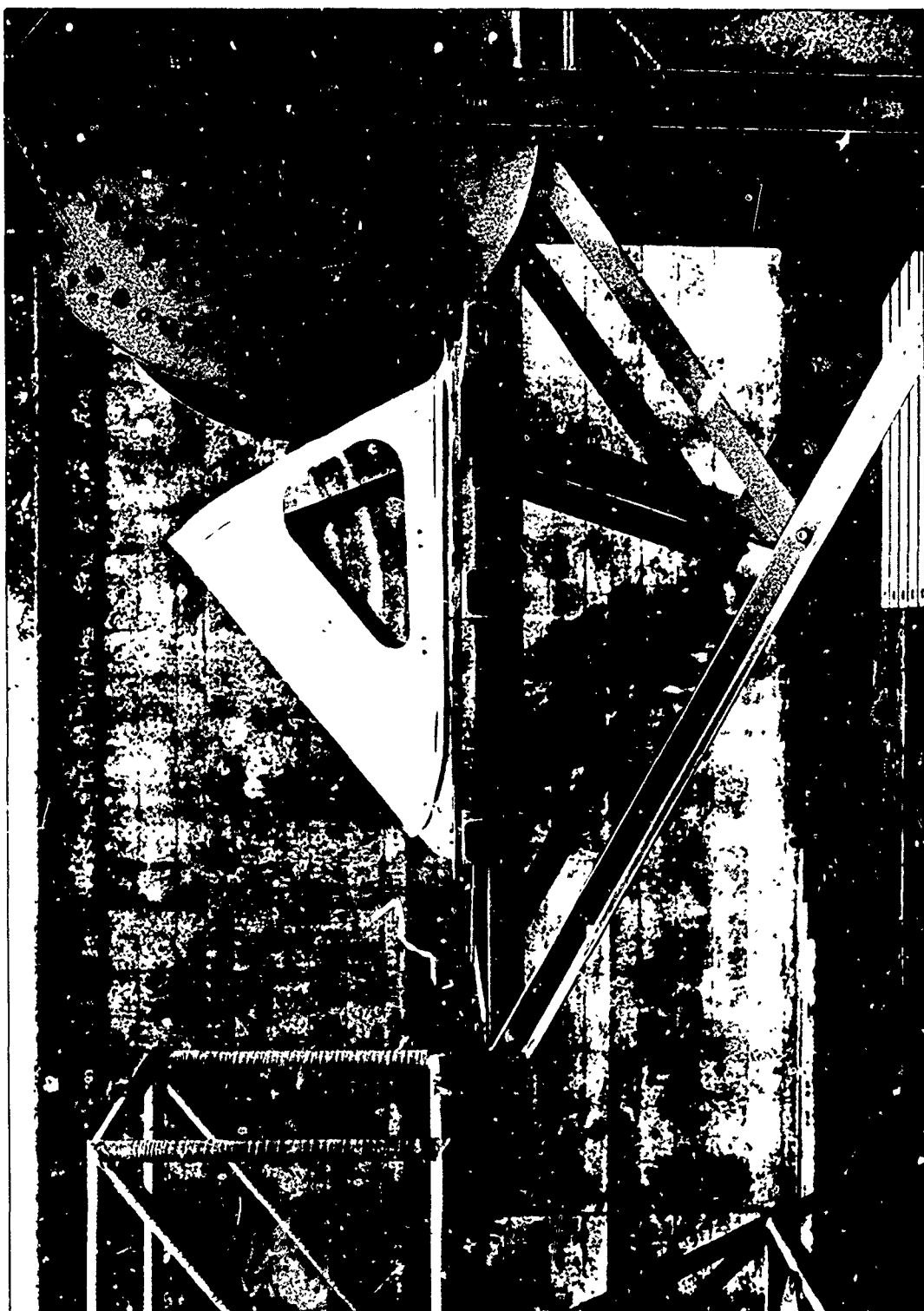
Fig.2 Windscreen specimen mounted for impact test

R. 65148

0·25" ANNEALED GLASS.

20 S.W.G. D.T.D. 610A PLATE.

0·25" 20% PLASTICISED VINYL.

0·75" TOUGHENED GLASS.

AIR GAP.

3/16" STRENGTHENED GLASS OR LAMINATE OF 2 mm WHITE GLASS + 0·02" VINYL + 2 mm WHITE GLASS.

3 LAYERS OF 1/8" GLASS.

RUBBER PAD. 1/16" THICK x 0·26" WIDE.

20 SWG L72 PLATE.

·12"

ATTACHMENT SCREWS 3/16" DIA. AT 2" PITCH APPROX (VARIABLE PITCH)

MOUNTING FRAME.

RUBBER SEAL 0·08" THICK X0·98" WIDE.

SPONGE RUBBER WASHERS 0·6" O.D. X 3/16" I.D. X 1/4" THICK.

SADDLE STRIP 10 SWG DTD 610 A.

CLAMP FRAME 18 SWG DTD 610 A.

FIG.3 ATTACHMENT FITTING AND PANEL DETAILS DRY AIR SANDWICH TYPE SCREENS

Fig.4

SME 90941/R

0.25 CLEAR WHITE STRENGTHENED GLASS.

GOLD FILM (HEATING)

0.25 VINYL

20% PLASTICISED VINYL.

0.045 30% PLASTICISED VINYL.

20 SWG L 72 PLATE.

0.04 30% PLASTICISED VINYL.

0.125 CLEAR WHITE ANNEALED GLASS.

0.75 TOUGHENED CLEAR WHITE GLASS.

ATTACHMENT SCREWS
3" DIA. AT 2" PITCH
16
(VARIABLE PITCH)

.16"

0.4"

MOUNTING FRAME.

THIOKOL

SADDLE STRIP 10 SWG L72

CLAMP FRAME 18 SWG L 72.
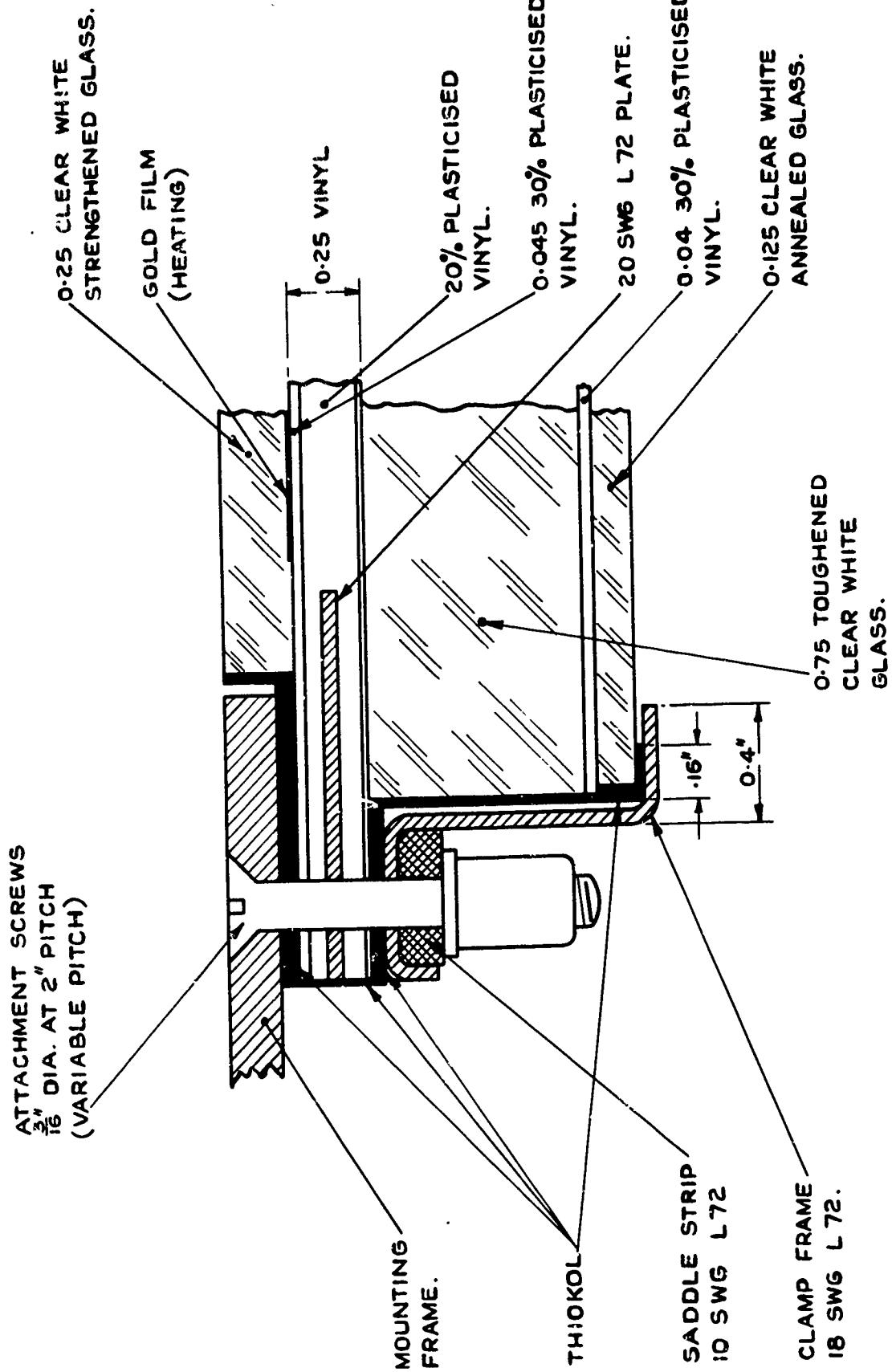
FIG.4   ATTACHMENT FITTING AND PANEL DETAILS   GOLD FILM TYPE SCREENS
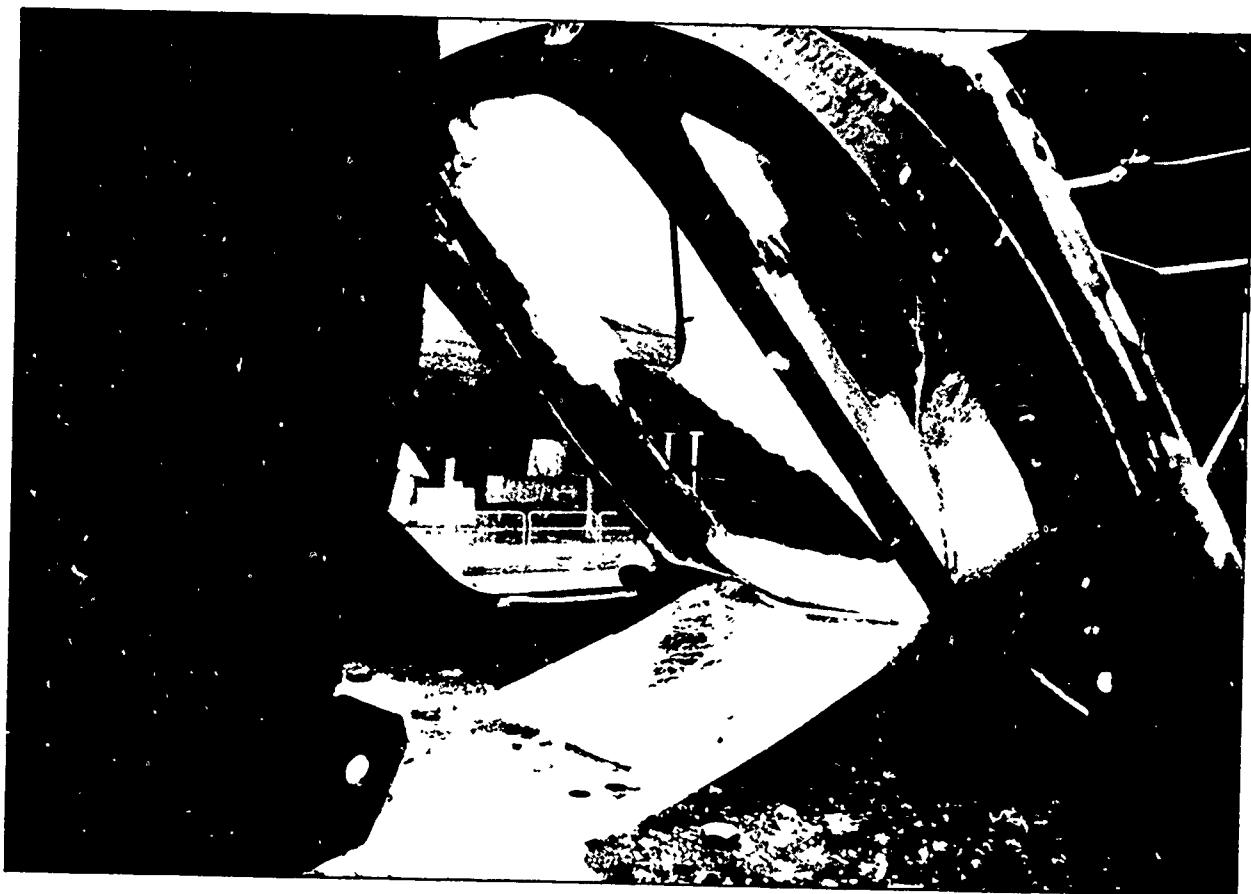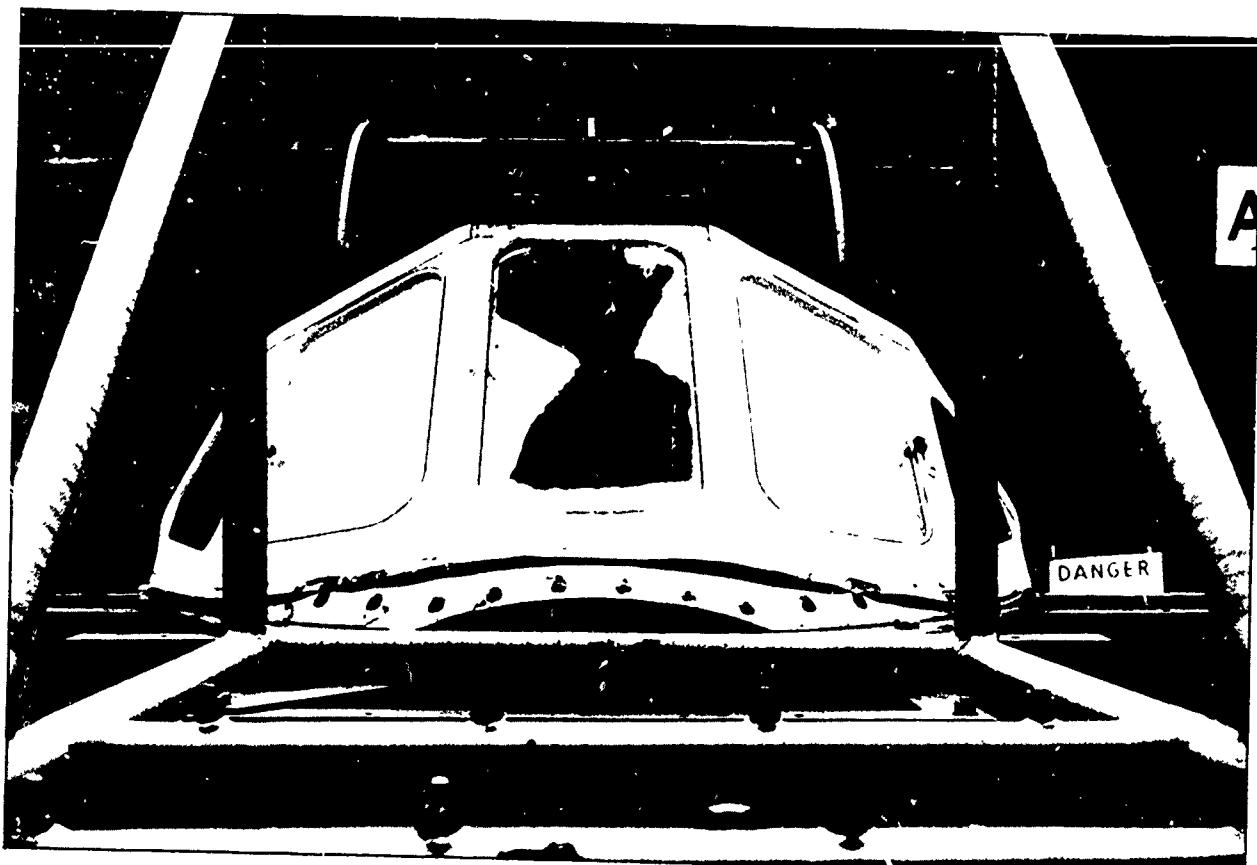
Fig.5

Impact of 4lb bird at 258kt on dry air sandwich centre screen at 5°c

Fig.5   Typical of complete failure

R. 65/48

Fig.6

Impact of 4lb bird at 269kt on heated (+ 50°c) side screen in OAT—9°c

Fig.6 Typical of severe damage

R. 65148
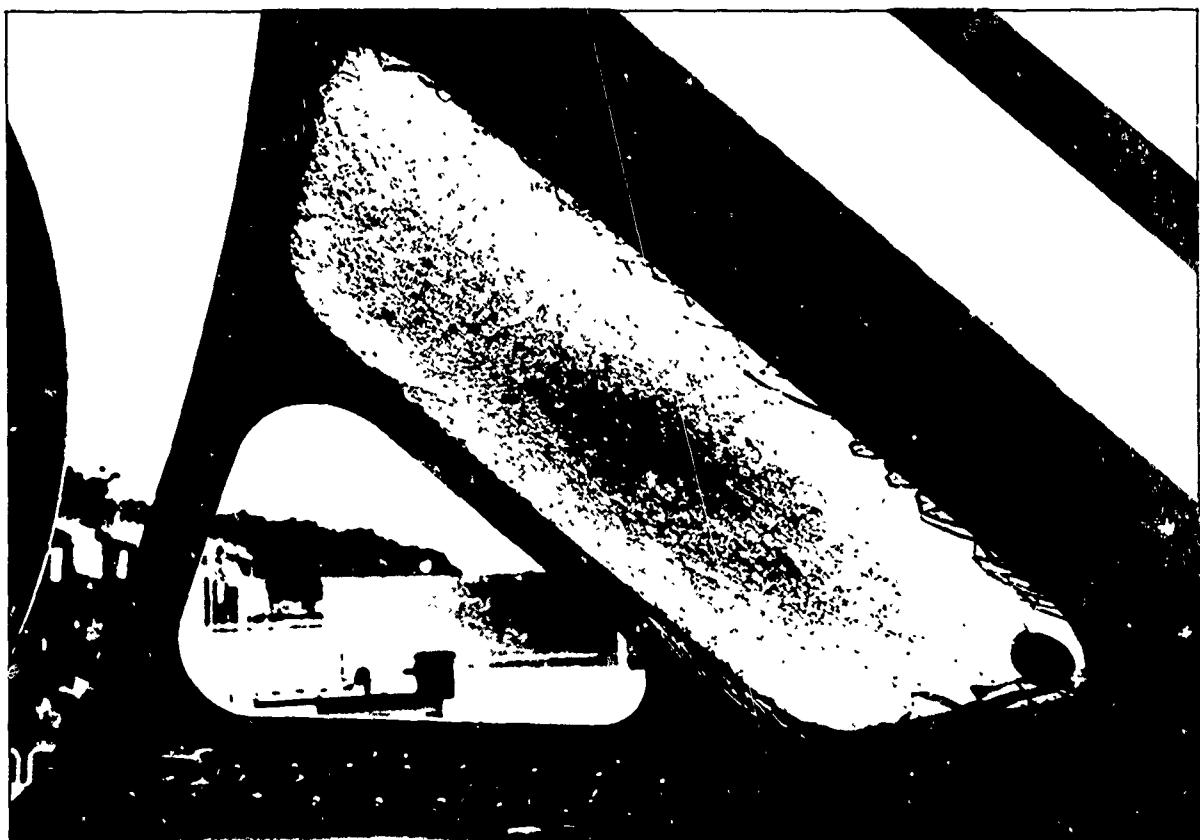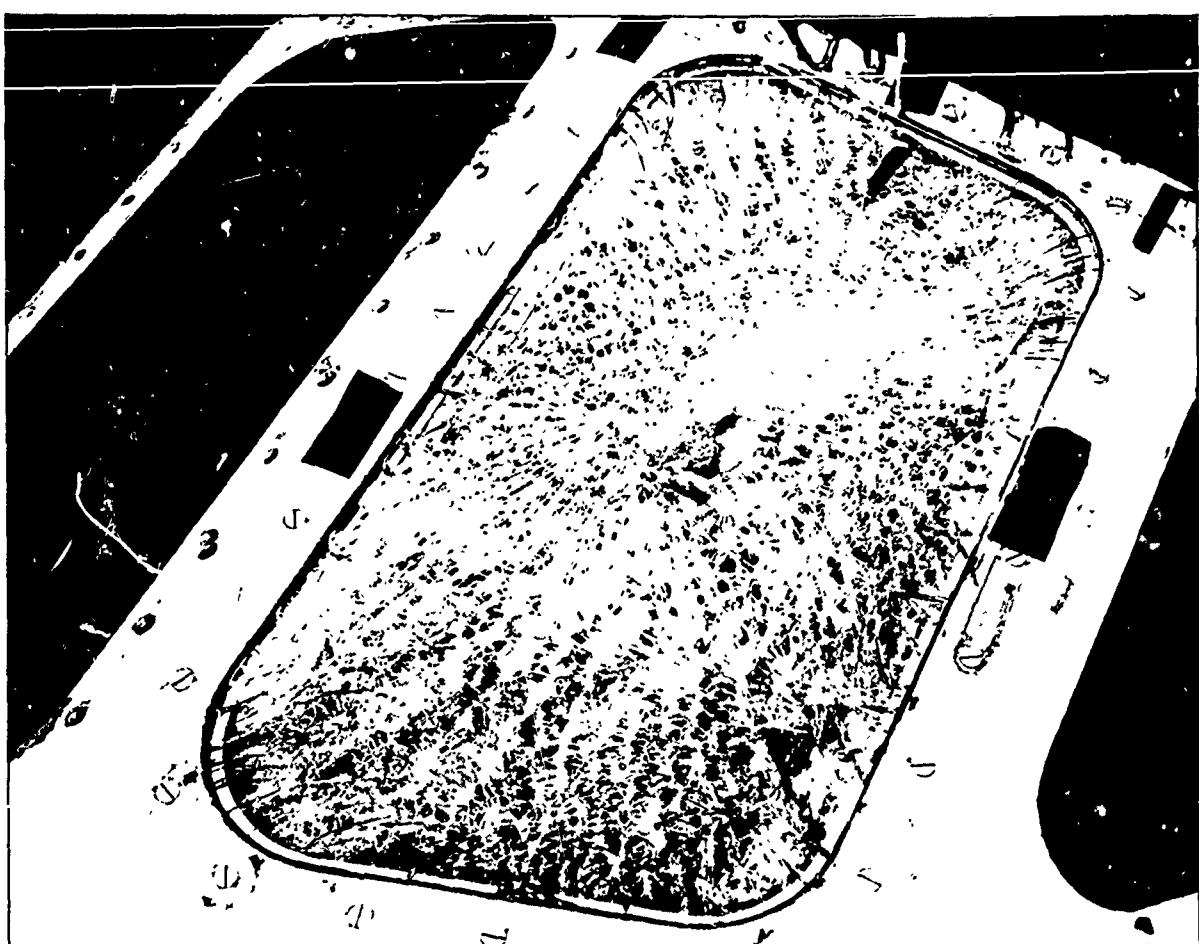
Fig.7

Impact of 4lb bird at 177kt on dry air sandwich side screen at—1°c

Fig.7 Typical of no penetration (Upper limit)

Fig.8   Neg. No. 755
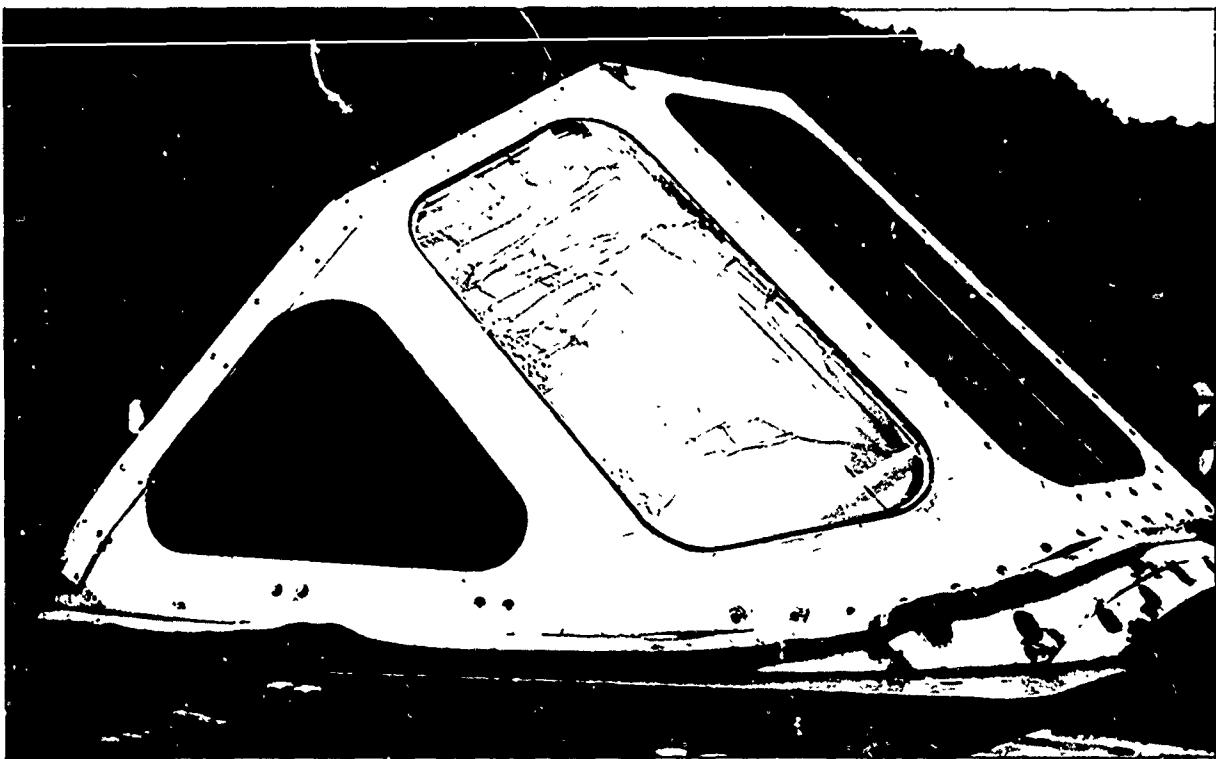
Impact of 2½lb bird at 285kt on heated (+50°c) side screen in OAT of —5°c

Fig.8   Typical of no penetration (Lower limit)
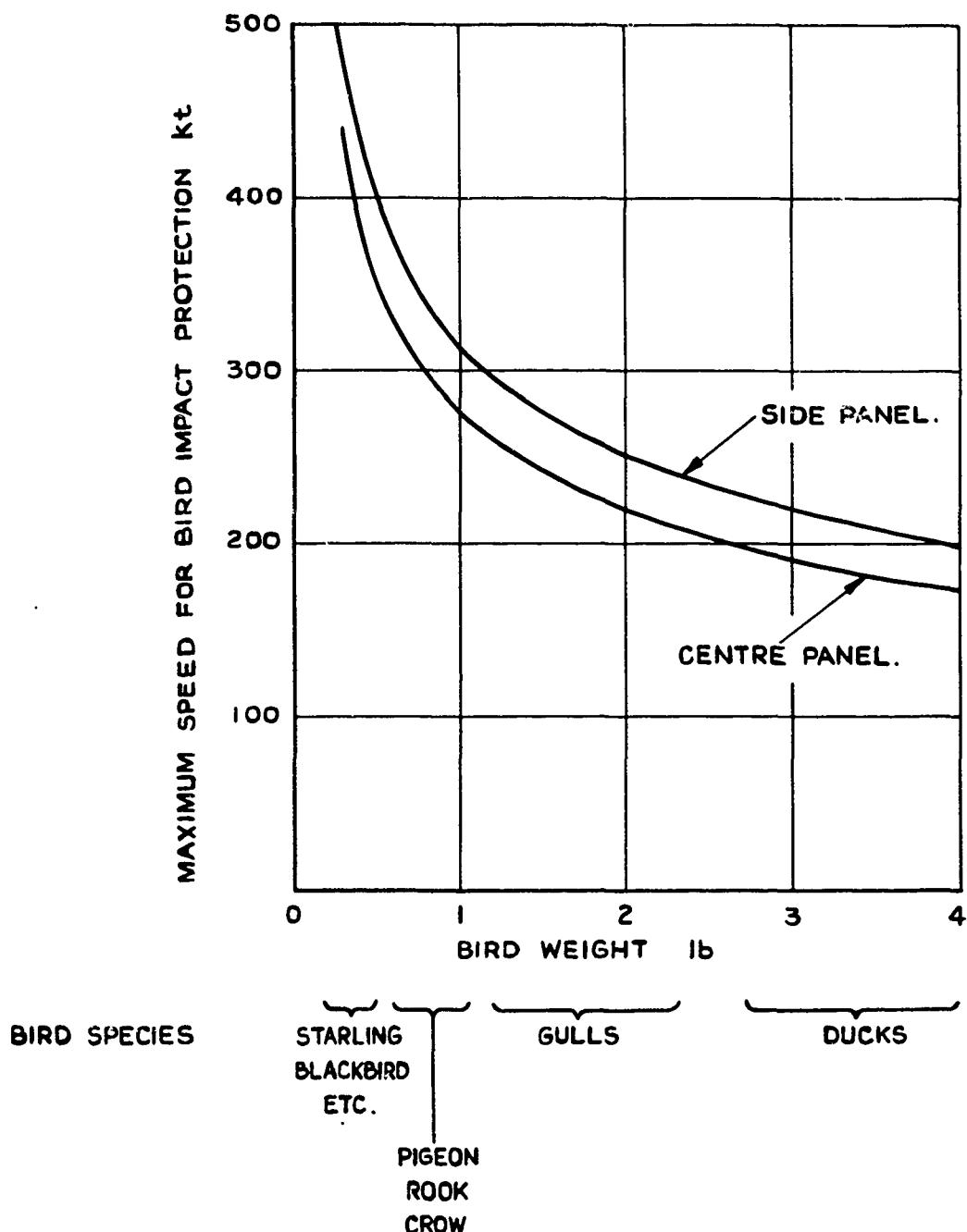
Fig.9

FIG. 9   BIRD IMPACT RESISTANCE OF VULCAN B MK I
DRY AIR SANDWICH WINDSCREENS

Fig.10   SME 90943/R
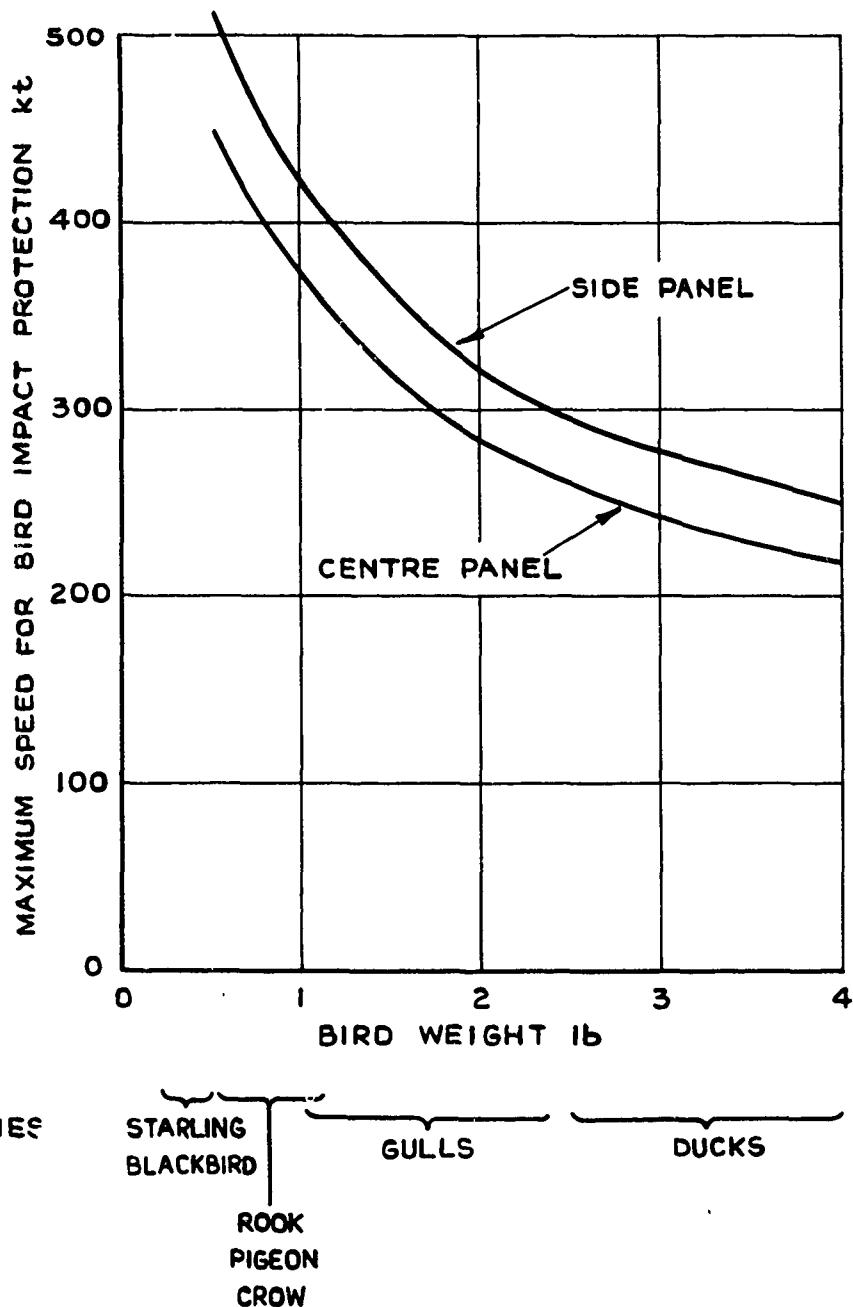
FIG. 10   BIRD IMPACT RESISTANCE OF VULCAN B MK 2
GOLD FILM WINDSCREENS

Fig.11

a. Impact of 4lb bird at 249kt OAT 20°c PVB layer at 50°c

Top edge clamp frame

U-shape clamp frame

b. Impact of 2lb 11ozs bird at 285kt OAT—1°c PUB layer at 50°c

Fig.11 Effect of lack of support at top edge of panel

629.13.012.134 :
620.178.7 :
598.2

McNaughtan, I.I.
Perfect, D.A.

BIRD IMPACT TESTS OF VULCAN AIRCRAFT WINDSCREENS

Royal Aircraft Establishment Technical Report No. 65148   July 1965

A description is given, and results presented and discussed, of a series of tests made to evaluate the bird impact resistance of Vulcan windscreens. The investigation included both dry air sandwich and gold film type panels impacted with 1 lb, 2½ lb and 4 lb birds.

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